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BY

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METHOD AND COSTS OF TREATMENT AT THE CALUMET & HECLA RECLAMATION PLANT[1]

By C. Harry Benedict[2]

This paper, describing the leaching practice at the Calumet and Hecla mills, Lake Linden, Mich., is one of a series on milling methods and costs being published by the United States Bureau of Mines.

GENERAL DESCRIPTION

The reclamation plant is located along the shores of Torch Lake at a slightly lower level than the concentrator itself. The entire location of the original concentrator, in connection with the present reclamation plant, has been ideal, more particularly as the leaching and flotation departments are common to both units. After 15 years of operation and with the reclamation sands just a little more than half exhausted it would appear that the remaining life of the deposit could be worked by the present plan, without decided changes or renewals of plant or equipment.

Torch Lake is one of a series of inland lakes in the Keweenaw peninsula of Upper Michigan, but it is distinguished by being on the same level as Lake Superior, with which it has navigable connection; and it is distinguished further by the fact that it is quite deep in comparison with its area. The mills were erected on the shore of this lake with no other idea than the desire to find room for the sand tailings, but considering the development of the mine and of the art of metallurgy in the 50 years following the foundation of the mills, no better site could have been found anywhere. The shore adjacent to the lake is relatively flat, so that all buildings are at approximately the same level, but the sloping hills running toward the shore permit of the uniform grade to a gravity railroad, and a trestle of moderate length gives the necessary elevation for gravity run to the ore bins and stamps. The mills were built close to the shore of Torch Lake, and for some years there was sufficient elevation so that the tailings ran into the lake by gravity, but as the deposit increased in area, elevation became necessary.

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1. The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6357."
2. One of the consulting engineers, U. S. Bureau of Mines.

Originally two mills were built, one known as the Calumet mill and the other as Hecla mill, and there are two distinct tailings piles with their centers about three-quarters of a mile apart and with clear water between, the two almost inclosing a bay from which is drawn the water for the pumping station. These tailings piles covered an area of about 152 acres at one time and vary in depth from nothing at the shore line to 120 feet at extreme depth. The reclamation plants were erected centrally to the north or Calumet pile, which at this date is exhausted. The Hecla bank was all conglomerate up to about 1900, but since that date the south or extreme end has been mostly amygdaloid tailings of much lower grade and there is a boundary line between the conglomerate and the amygdaloid, where the material, as dredged, is a mixture of the two.

At the beginning of the mining operations in the late sixties the ore was running better than 100 pounds to the ton by assay, and the metallurgical methods were naturally crude compared to present-day standards. The ore increased in richness for some years after the opening of the mines, and tailings losses of 20 pounds and more to the ton were not out of the ordinary. In those years the smelters required a very high-grade product, and as the fine copper could not be concentrated profitably to smelter requirements, practically no effort was made to save the slimes until about 1884, when buddles or circular slime tables were introduced. Neither was any effort made, except spasmodically, to do any grinding other than that by the original stamp, which crushed all material to pass through a 3/16 inch round-opening screen. This made for very rich tailings, and it was not until 1898, with the introduction of Wilfley tables, soon followed by fine grinding in Chilean and later in Hardinge mills, that any serious attempt was made to reduce the losses of fine enclosed or attached copper. The introduction of this more modern machinery was coincident with a rapid falling off in the quality of the ore sent to the mill, owing partly to the lessening in grade of the deposit underground and partly to the fact that lower-grade ore could be treated economically. A further decided loss in copper followed the installation of a regrinding plant in 1908 and made it appear that the tailings subsequent to that date might not be profitably reworked, although they still contained about 9 pounds of copper to the ton. These tailings were accordingly segregated on one portion of the Calumet pile. With the discovery of the leaching process in 1912 and the adaption of flotation a few years later, it became evident that these apparently worthless tailings were of economic value.

That these tailings had commercial possibilities was recognized for a great many years before any effort at recovery was begun. Until the development of modern fine-grinding machinery, coincident as it was in the Lake Superior district with the introduction of the low-pressure turbine and consequent cheap electric power, it was not felt that the time was right for beginning operations. Then at first the plans were only for finer grinding and Wilfley table treatment, and it was the expectation that the recovery might not exceed 40 per cent. Even

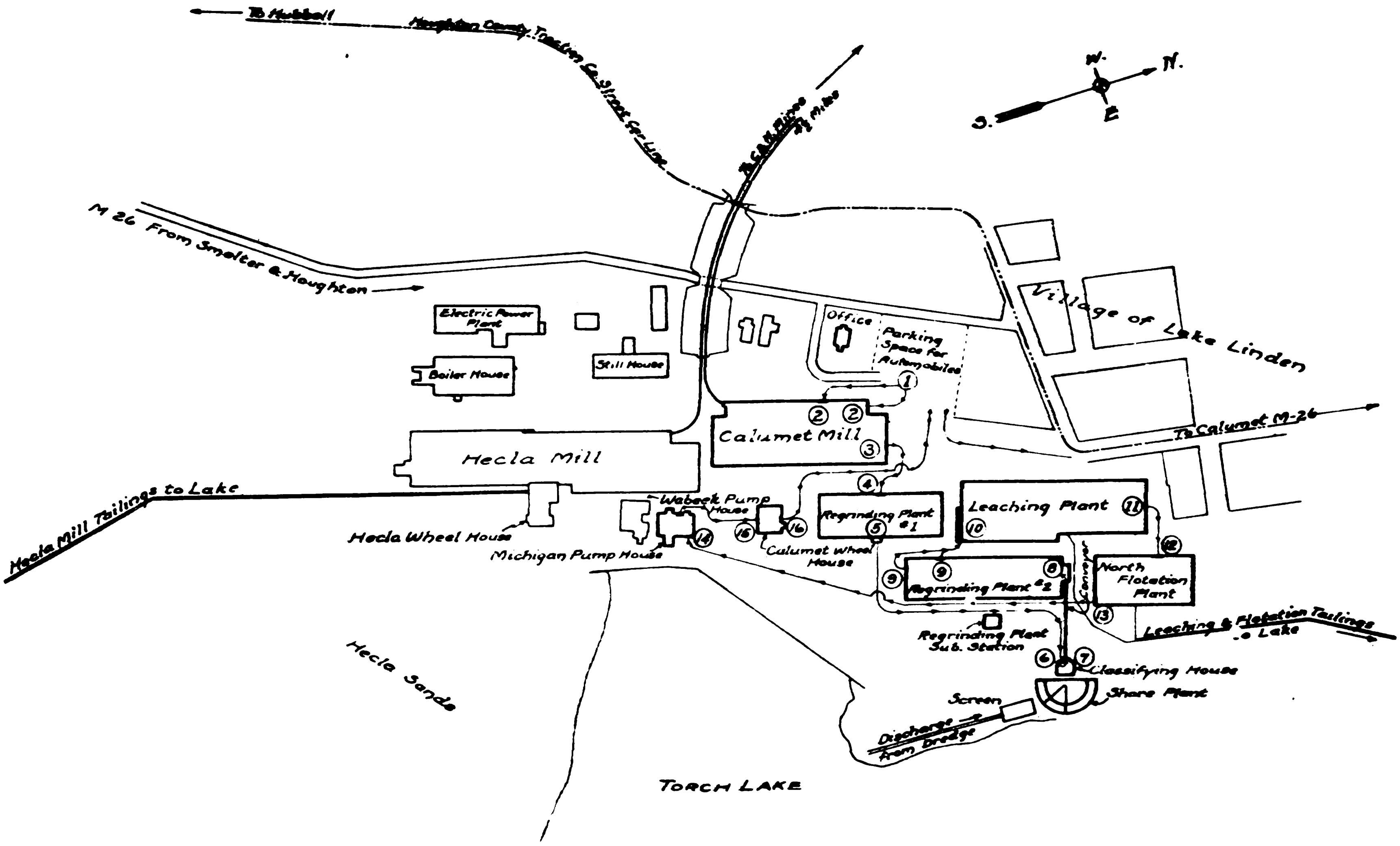

Figure I.- Calumet and Hecla mills, Lake Linden, Mich.

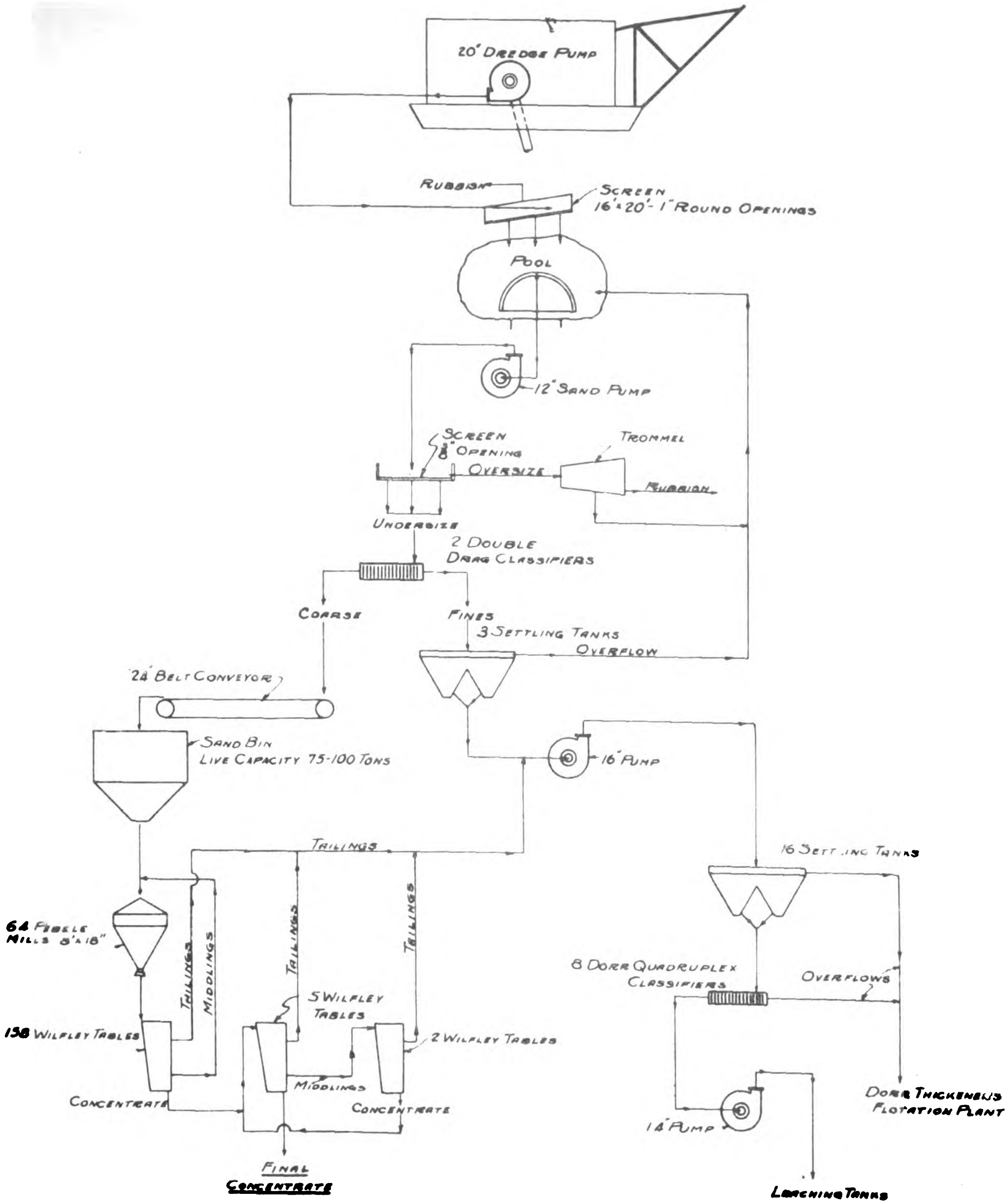

Figure 2.- Gravity flow sheet of Calumet and Hecla reclamation plant

this was attractive, and work was begun in 1912. The grinding plant was not yet in operation, however, before the leaching process was developed, which promised to double the anticipated recovery. Construction work was started in 1914 on the leaching plant, designed to treat sand, and experimentation was continued on the treatment of slimes by the same process. The rapid development of flotation, however, and its adaptation at the Calumet & Hecla plant to native copper, made it advisable to discontinue work on the leaching of slime, and a flotation plant was erected for this material. This again increased the recovery, so that about 90 per cent of the values contained in these tailing piles will probably be obtained by the present methods. Inasmuch as the recovery on the ore originally was about 75 per cent, over 95 per cent of the metal contents of the Calumet & Hecla conglomerate lode as mined will be obtained as refined copper, a record probably unique in the history of any copper-mining operation.

Although the commercial possibilities of these deposits had been recognized long before recovery plants were erected, their treatment was not sufficiently imminent to prevent surface contamination. All the rubbish of the stamp mills and from the adjacent towns was deposited on top of these sand banks, and although this rubbish does not constitute a large percentage of the total weight, it amounts to thousands of tons of every conceivable kind and size of material, and any plan for the reworking of the sand had to take into account a mixture of ashes, hoop iron, wire cable, launder plates, and submerged logs. After 14 years of operation, the suction-dredge originally chosen has been in commission without at any time having had serious difficulty in operation.

The reclamation plant as at present constituted consists of five units separately housed as follows:

1. Dredge
2. Shore pumping plant and classifying house.
3. Regrinding plant.
4. Leaching and distillation plant.
5. Flotation plant.

Figure 1 shows a diagram of the units of this plant in connection with the other mill buildings. Figure 2 is a flow sheet.

DREDGE

It was recognized at once that a suction-dredge would be the only possible means of reclaiming these tailings, because of the depth of the deposit and the severity of the climate. It was not feasible to develop a dredge by experimentation on a small scale, because from the very nature of the problem large-scale operation alone was possible. No dredge had ever been designed to dig 110 feet below the water line. A bucket dredge was considered entirely unfit because of the depth and also because of the fact that although a bucket dredge might handle rubbish to good advantage, the sharp, coarse sand would be very hard upon the innumerable bearings. Furthermore, it was thought impossible to operate such a dredge in winter time in the Lake Superio district, with the thermometer frequently reaching 20° below zero.

The dredge finally adopted was developed with the aid of the Bucyrus Co., of South Milwaukee. It is a steel-hull dredge 56 feet wide and 110 feet long, with an overhanging deck 8 feet wide. As originally installed, having in mine the amount of oversize rubbish to be handled, the dredge was provided with two dredging pumps. The first discharged into a 1-1/4 inch revolving screen for removing rubbish, the undersize going to a sump from which a second pump elevated the material and discharged it through the pontoon line.

After considerable trouble with the handling of the oversize rubbish in this way a method was finally devised of using but a single pump for dredging the sand directly from the lake and discharging it through the pontoon line to a stationary screen at the shore plant. This eliminated entirely the revolving screen on the dredge and the second dredge pump and resulted in a tremendous saving of power and maintenance. It is surprising what large pieces of timber, rope, and even steel plate can be picked up by the pump and carried through 3,000 feet of the 20-inch discharge pipe to the receiving pool on shore without choking pump or pipe.

In winter the ice on the lake is always at least 2 feet thick, 20° below zero is not uncommon, and usually for two or three weeks the temperature is below zero daily. However, these conditions have caused no cessation of work in the 14 years of operation, and the dredge has less difficulty and loss of time in midwinter than has the railroad that brings ore from the mine to the mill. At first to meet winter conditions efforts were made to cut the ice from about the dredge and haul it away. When the revolving screen was discontinued, however, so that the second dredging pump was not required, this pump was connected to a pipe surrounding the dredge, and water under pressure was discharged through a series of nozzles about 10 feet above the deck of the dredge. The agitation from this water was sufficient to keep the ice from forming freely and also to melt such ice as had been formed adjacent to the dredge. An efficient water pump has since been installed for this purpose, and it is necessary to operate it only for a few hours daily in extremely cold weather.

The dredge pump itself has a 20-inch diameter inlet and outlet, with impellers 55 inches in diameter, operating at 360 r.p.m., and is equipped with a 1,250-hp. motor. The pump casing is split vertically and is lined throughout.

Various types of material for liners have been used, and although the best absolute results are obtained with manganese steel, chilled cast iron made in the local foundry is much the cheapest material per ton dredged. In addition to the main dredge pump, and an auxiliary pump for supplying water to prevent ice formation, there is a four-inch centrifugal pump for service water and an 8-inch centrifugal pump for supplying water at 75 pounds pressure for agitating and breaking down the sand at depth. The dredge suction mouth is supplied with nozzles reaching out in all directions along its periphery, and these nozzles discharging water under pressure keep the sand in agitation and break down the bank in advance of the digging ladder. The pipe for supplying this water is carried on the digging ladder and connected to its pump through a universal joint. This type of agitation has proved satisfactory, and at no time has the lack of a rotary cutter been felt.

When the dredge gets into certain portions of the bank the material tends to hold up beyond the natural angle of repose, and consequently caves of considerable magnitude occur. Only once has a cave-in proved serious, when the digging ladder was caught under an avalanche of sand. To release it, it was necessary to abandon the regular suction of the dredge and install a new suction, using the original dredge pump, operating the temporary suction independently by means of tackle from above, lowering it gradually through the accumulated sand, and adding more pipe with depth until the ladder was finally reached and freed. The 10-day delay because of this accident, and a second shutdown of three weeks when the dredge was dry-docked and the hull scraped and painted, have been the only interruptions to continuous service during 14 years of operation.

The suction ladder consists of two longitudinal latticed girders thoroughly fastened and well braced. It is 141 feet from center of suspension to the end of suction, and will permit of dredging to a depth of 110 feet. It carried the outboard suction of lap-welded pipe and also an 8-inch water pipe for supplying water under pressure for breaking down the sand. The center of the dredge pump is on the same center line as the pivot of the suction ladder, and the suction pipe is connected to the pump by an elbow, swiveled on this same center line. Near the outer end of the suction ladder the lower block of the hoisting tackle is attached, and the upper block is attached to the bow gantry, forming part of the hull.

The dredge is not self-propelling, but is operated by swinging lines fastened to anchors in the water and to deadmen along the shore. There are two 4-drum winches for operating the lines, two drums of which are for the ladder swing, two for the bowline swing, two for the stern-line swing, one for the stern line, and one independently operated for hoisting the suction ladder. The bow swing lines are 3/4-inch diameter, the ladder and stern lines are 7/8-inch, and the ladder hoist rope is 1 inch in diameter; all are of plow steel. All pumps and winches are electrically driven, but there is a small boiler on the dredge to provide steam for heat and also for operating capstans when the electric power is cut off.

Electricity is supplied to the dredge at 2300 volts, the power lines being supported on towers attached to the pontoons carrying the discharge pipes. The main dredging pump motor is 1,250-hp. rating and consumes about 900 kilowatts when working through its maximum discharge pipe of 3,000-foot length. An additional 200 kilowatts is consumed by the 8-inch and 4-inch water pumps. Water rheostats control the speed of the pump with a variation of about 30 revolutions, from the minimum of 335 r.p.m.

Inboard and outboard pipe is of 21-inch diameter outside and the discharge line consists of the same kind of pipe, mostly in 60-foot lengths, carried on steel or wood pontoons. The pontoon pipes are connected by means of rubber sleeves, and although other types of flexible connections have been tried, especially ball joints, everything has been abandoned in favor of the rubber sleeves. The sleeves are held on by split steel bands which arrangement, in connection with the beaded ends of the pipe, gives a simple flexible joint and one that does not cause much trouble. Sleeves wear as long as five years.

The pontoon pipe discharges at a fixed point on the shore into a stationary screen 16 by 20 feet, with round openings 1 inch in diameter. This discharge is placed so that the sand runs from the screen into a pond or reservoir which supplies the pumps in the shore plant about to be described. Not much rubbish accumulates on the screen, but it may consist of large pieces, including many relics of early days. A chain 6 feet long was once removed from the screen; also pieces of cast iron, innumerable rocks, and logs up to 16 inches in diameter.

The dredge has a rated capacity of 10,000 cubic yards per day, which has been realized. No facilities have ever been at hand to make a definite test of its efficiency, and there is so much variation in the size and nature of the sand to be pumped, the length of the discharge line, the condition of the impeller and pump casings, and depth of suction, that a test would be of little value. In the winter about 16 hours, including delays, are required to do the necessary work, and sometimes during the summer, when the pontoon line is 3,000 feet long and the sand is fine and scattered, continuous operation is necessary.

No effort is made to synchronize the operation of the dredge with the shore plants, which must run uniformly 24 hours per day. The capacity of the reservoir in front of the shore plant is such that the dredge can shut down two or three days at a time without the plants being short of sand. A dredge is necessarily irregular and intermittent in its operation, even when working under the best of conditions, and under the varying conditions met in this operation there is no possibility of supplying sand in either uniform quantity or dilution.

The general method of operating the deposit and the measurement and control of the work are carefully studied from day to day. Fortunately the United States Government had made accurate soundings in Torch Lake before the mills were operating for any length of time, so that the extent of the deposit both laterally and in depth is accurately known. A sectional model has been made, consisting of vertical wooden pegs fastened into a horizontal board representing a base line. These pegs indicate conditions for each 50-foot station and by means of different colors show lake bottom, lake level, and recoverable sand. Frequent soundings keep this model up to date, and operators on the dredge know at all times at what depth to expect sand and to what extent. Ranges along the shore and floating buoys assure accurate knowledge as to the position of the dredge, and a section of the model in the pilot house provides complete information as to conditions of deposit. The original lake bottom is fortunately a compact sand that resists dredging with this type of machine, and much of the area is as clear of tailings after dredging as a surface operation could be.

For 1929 the cost of dredging alone, including all replacements and renewals, was 5.63 cents per ton dredged. This cost comprises 34 per cent for labor, 46 per cent for power, 18 per cent for pipe line and pump renewals, and 2 per cent for other supplies. These costs are for an average discharge line of about 2000 feet, and vary somewhat with the size of sand, length of line, and other factors. The costs are showing a downward tendency from year to year.

SHORE PUMP PLANT AND CLASSIFYING HOUSE

This plant is built upon a concrete dock constructed by driving piles through the sand down into the original lake bottom and upon these piles putting a cap of concrete 3 feet 6 inches thick. The shore plant contains a 12-inch Morris centrifugal pump for the elevation of the sand, stationary screens for removing fine rubbish, drag belts for separating the coarse sand that requires regrinding from the fine that does not, pumps for handling this fine sand, and the belt conveyor for conveying the coarser sand from this plant to the top of the regrinding plant. In the pond or reservoir in front of the shore plant into which the dredge sand is discharged is a semicircular row of piles having a radius of 35 feet on which is constructed a track. Supported on this track and pivoted in front of the plant is a structural steel bridge 55 feet long, which carries the suction pipe of the pump in the shore plant. The suction pipe works on swivel joints, so that it can travel through an angle of about 150° and its outer suction end can be raised or lowered vertically through an angle of 90°. The effect of this is to get a storage capacity for this suction pump in a V-shaped section along about one-half of the circumference of the 55-foot circle and to a depth of 30 feet below the water line. This a storage reservoir capacity equivalent to about 20,000 tons of sand is obtained. From any part of the reservoir the sand may be reclaimed, depending upon the position of the suction pipe carried on this swinging bridge. In reality it is a stationary dredge working under uniform conditions as to length of suction line, so that uniform capacity is obtained and the retreatment plants are kept operating under uniform conditions, a necessity for efficient metallurgical practice.

To guard against delays in the shore plant, the original design called for two pumps so placed that by swinging a suction elbow through 180° one pump could be replaced by the other. Delays have been so infrequent, however, that such changing of parts as is necessary can be done during the regular four-hour shut-down once a week, so that only a single pump has been necessary. This pump has a 12-inch suction and discharge, is split horizontally, and is lined throughout. The impeller is 40-inches in diameter running 375 r.p.m. direct-connected to a 200-hp. motor. The discharge of this pump goes into a large receiving box fitted with an overflow for the excess water, and as this water carries considerable fine sand it is returned to the storage pool. Circulation of water is very useful in winter, as the agitation caused thereby aids in keeping the pool free from ice. The receiving box is provided with four openings, gate controlled, through which the sand and water flow to stationary screens with 3/8-inch openings. These screens are for the purpose of removing the finer particles of rubbish. The undersize of these stationary screens is fed to two double drag-classifiers, each fitted with 20-inch belts, these belts being provided with 6 by 4 inch angle irons, 24 inches long, as drags. The discharged product of these drag belts is fed by chutes to a 24-inch belt conveyor, and the overflow, after suitable dewatering, is pumped directly to the same sand and slime-classifying system that takes also the tailings of the regrinding plant.

The life of the belt conveyor is over three years, during which time it handles about 3,000,000 tons sand. The cost of the total operation of the plant for the year 1929 was 2.50 cents per ton. Of this cost 55 per cent was for labor, 26 per cent for power, and 19 per cent for supplies, chiefly pump repair parts and pipe.

REGRINDING PLANT

The material treated in the regrinding plant (fig. 3) is the coarse sand classified out by the drag belts in the shore plant and fed to the top of the plant by means of a belt conveyor. This belt conveyor is 275 feet between centers, runs at a speed of 500 feet per minute, and has an inclination of 2-1/2 inches to the foot. It discharges into a receiving bin, which has sufficient storage to supply the mills for about 30 minutes. In the bottom of this receiving bin are discharge openings, fromwhich the relatively dry sand is run at a uniform rate and fed by means of water jets into launders running down either side of the plant and discharging by means of cut-out gates into dewatering boxes for feeding the conical mills.

The building itself is 122 by 431 feet and contains 64 Hardinge mills, 8 feet by 18 inches, driven individually by 40-hp. motors connected by means of flexible couplings to herringbone pinions driving corresponding herringbone gears. The mills revolve at 26 r.p.m., are lined with either Belgian silex or domestic quartzite, and use flint pebbles for the grinding medium: The conical mills were among the first built by the Hardinge Co., which accounts for the short cylindrical length. These conical mills and motors are carried on a structural steel framework or floor about 12 feet above the Wilfley table floor. The mills are in two rows of 32 each and are served by a 15-ton traveling crane which can pick up a full mill. All relining is done at the end of the plant, where piers are provided for this purpose. By the use of two extra mills it is usually possible to take a worn-out mill and feplace it within an hour by a newly lined spare.

The mills are fed by a gate in the overhead launder handled by a lever from the conical-mill floor. The material cut out in this manner is run into a dewatering box, from which a plug discharges the thickened product into the feed scoop of the conical mill. The discharge of the mill is run into a disgributing launder and fed directly to Wilfley tables, the product of the two mills going to five Wilfleys. The concentrates from the Wilfleys are reconcentrated on other tables and the final concentrates are pumped into a box from which they are conveyed by means of a drag belt into concentrates cars. Table middlings are returned to the conical mills for finer grinding. The tailings from the Wilfley tables join the fine product from the drag belts in the shore plant, and this combined material is pumped by means of a 16-inch centrifugal pump to a classifying section in the leaching plant where sand for leaching is separated out from the slime for flotation. The leaching plant and the flotation plant are described in detail in information circular ~~6357~~ 6364 Milling Method and Cost at the Conglomerate Mill of the Calumet & Hecla Consolidated Copper Company.

The grinding plant has a capacity of about 3,000 tons per 24 hours. The mills have a cylindrical length of only 18 inches and the capacity per mill is small. All grinding is in open circuit which was standard practice at the time the building was designed and the changes necessary to go to closed circuit were so extensive that it has never been attempted. Complete closed circuit is not practical because of the fact that the metallic particles would remain in circuit and build up to an extent that would seriously interfere with grinding efficiency. It would be possible, as has been done in other installations, to bleed the circuit either by means of a hydraulic classifier or by tabling a ceftain percentage of the pulp to relieve the circuit of the free metallic particles. Because of the limited life of the deposit for which this plant was designed, it has beemed better to endure this mechanical inefficiency rather than to expend the capital that would be required to bring this in line with modern practice.

The use of pebbles instead of steel balls has proved to be economic. At various times the use of steel has been tried, always with a decided increase in capacity but at a prohibitive cost. The hardness of the conglomerate ore is as great or greater than that of steel, so that there is an excessive consumption of the grinding media. Such tests as have been run indicate that consumption of steel balls is at least 80 per cent as great as that of pebbles, compared by weight per ton of material ground. With consumption of steel balls running from 3-1/2 to 4 pounds per ton of sand ground and with a cost of 3-1/2 cents per pound of ball, we have a total cost of from 12 to 14 cents with the use of balls for a grinding medium as against 4 cents with the use of pebbles.

The tonnage treated in the year 1929 was 979,555 tons. The cost of operation in cents per ton for the corresponding year was as follows:

General expense		1.98
Sand conveying and distribution		1.73
Grinding:		20.29
Attendance	1.35	
Power	10.90	
Pebbles	3.33	
Lining	3.93	
Other supplies	.78	
Table treatment		3.11
Total		27.11

SUMMARY OF RESULTS

All material treated passes through the dredge and shore plant, but in the shore plant there is a separation of reground sand from that which does not require finer grinding. The result is that of the total tonnage dredged, approximately 66-2/3 per cent goes through the regrinding plant. After regrinding, the fine material is separated into leaching and flotation feed in the ratio of 80 per cent leaching to 20 per cent flotation.

The total cost per ton based on tonnage dredged, for the reclamation plant in 1929 is as follows:

	Cost, cents
General administration, mine and mill	3.8
Dredge & pontoons	5.6
Shore plant and belt conveyor	2.5
Regrinding	17.2
Leaching	17.8
Flotation	1.8
Miscellaneous	.8
Total	49.5

Tonnage treated	1,546,000
Assay heading, per cent	.973
Assay tailings, per cent	.120
Pounds copper produced	25,991,000
Pounds of copper per ton treated	16.81
Cost per ton treated— cents	49.5
Cost per pound copper— cents	2.94

As the deposition of these mill tailings in the lake dates back to the beginning of milling operation it was estimated that some 34,500,000 tons would be available for treatment. The total tonnage reclaimed up to January 1, 1930, was 18,973,000 tons, from which there was produced 212,598,000 pounds of copper, being 11.21 pounds of copper per ton of sand. This was at a cost per ton treated of 54.8 cents and at a cost per pound of copper produced of 4.89 cents, exclusive of smelting and selling.

This plant is one of the few, and certainly the most extensive, devoted to the reclaiming of concentrator wastes. The returning of the waste sands from the lake into the treatment plants is unique not only in method but in magnitude, and as a purely dredging proposition is probably the deepest practiced anywhere in the world. With fine grinding, table treatment, leaching, and flotation all necessary to efficient recovery, it exemplifies in its treatment most modern methods of extraction, and the resulting copper is obtained at a cost per pound comparable to that of the lowest primary producers.

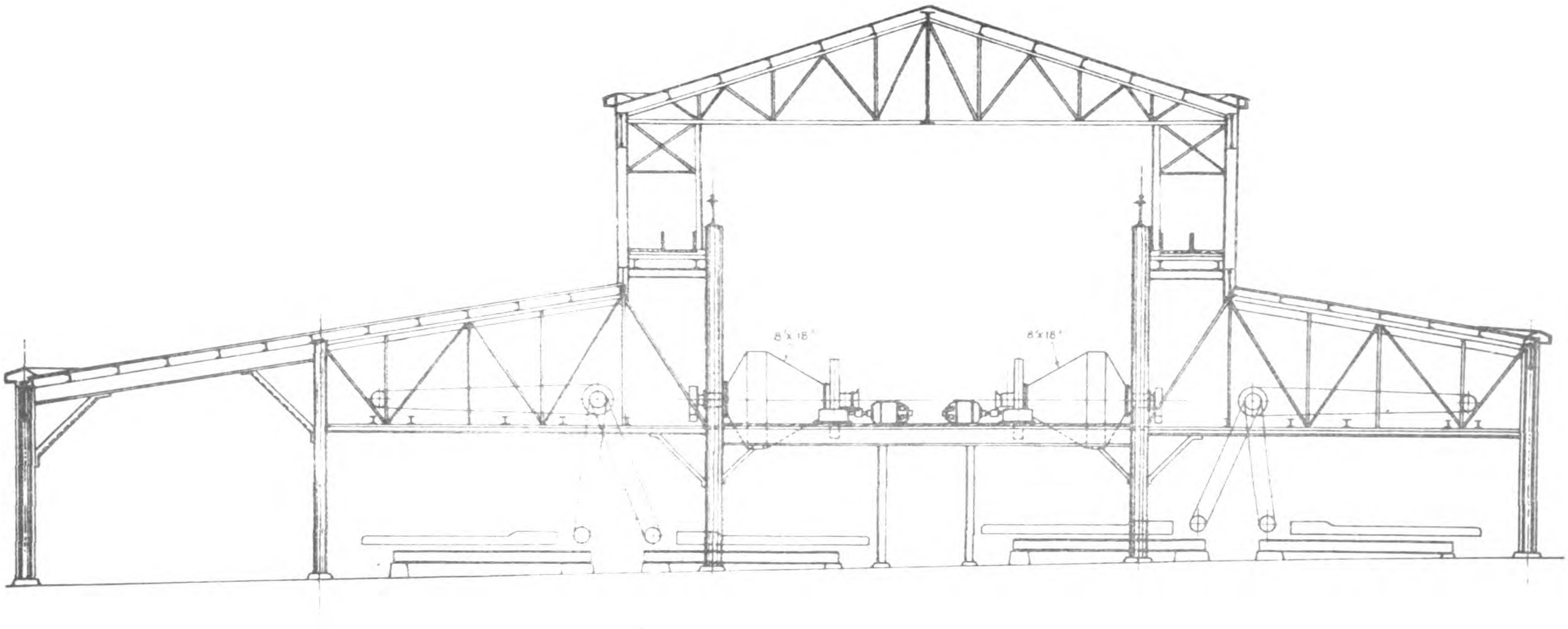

Figure 3.- Sectional elevation of No. 2 regrinding plant